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(54) **DOPED SUBSTRATE REGIONS IN MEMS MICROPHONES**

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H04R 19/00 (2006.01)
(Continued)

(52) **U.S. Cl.**
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(Continued)

(58) **Field of Classification Search**
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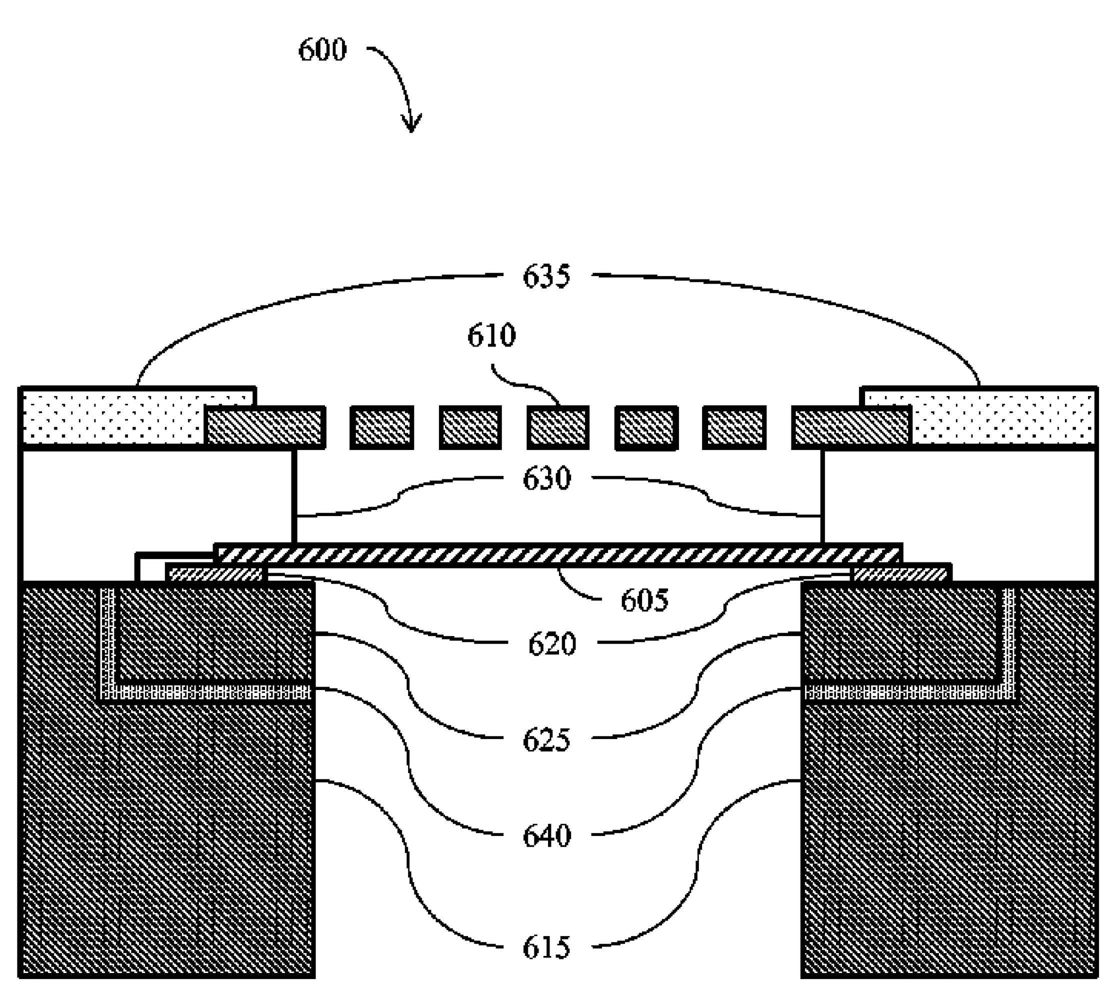
(57) **ABSTRACT**

Systems and methods for preventing electrical leakage in a MEMS microphone. In one embodiment, the MEMS microphone includes a semiconductor substrate, an electrode, a first insulation layer, and a doped region. The first insulation layer is formed between the electrode and the semiconductor substrate. The doped region is implanted in at least a portion of the semiconductor substrate where the semiconductor substrate is in contact with the first insulation layer. The doped region is also electrically coupled to the electrode.

18 Claims, 12 Drawing Sheets



(51) **Int. Cl.**

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H04R 1/04	(2006.01)
H04R 31/00	(2006.01)

(52) **U.S. Cl.**
CPC ***H04R 31/006*** (2013.01); *H04R 2201/003* (2013.01)

(58) **Field of Classification Search**
USPC 381/173–175; 257/704, 723, 724, 731, 257/774, 782, 415–418
See application file for complete search history.

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PRIOR ART

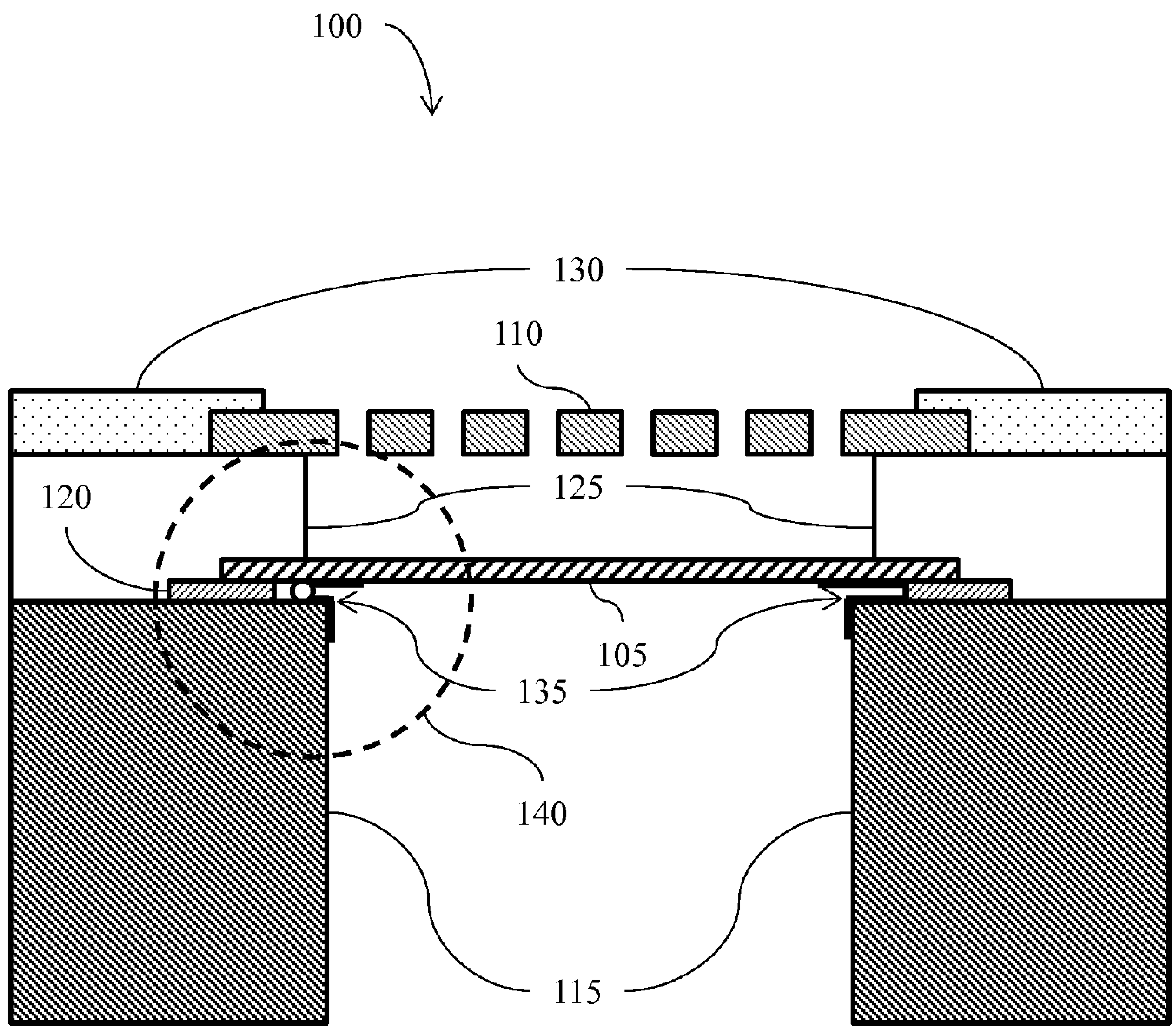


Fig. 1

PRIOR ART

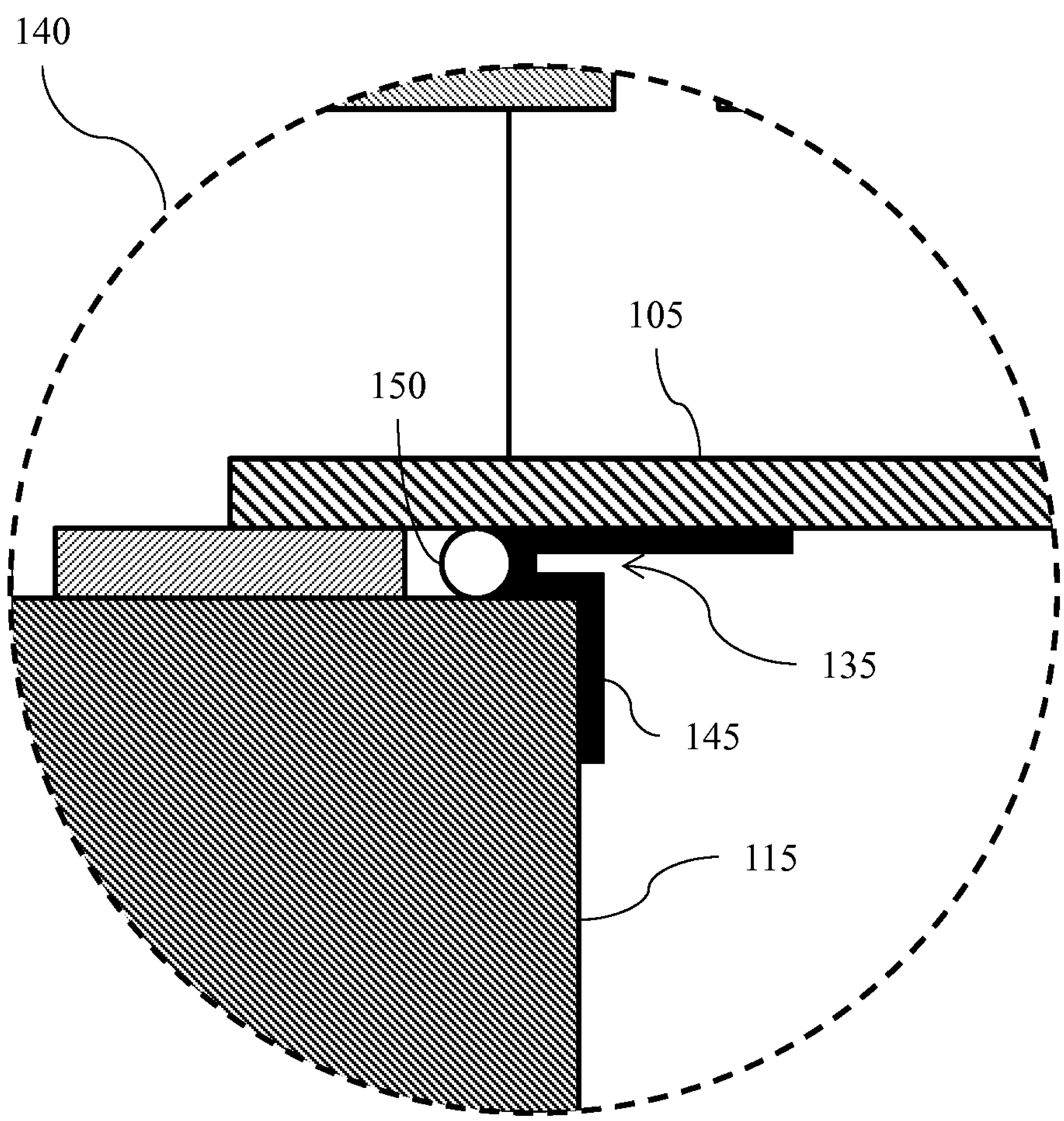
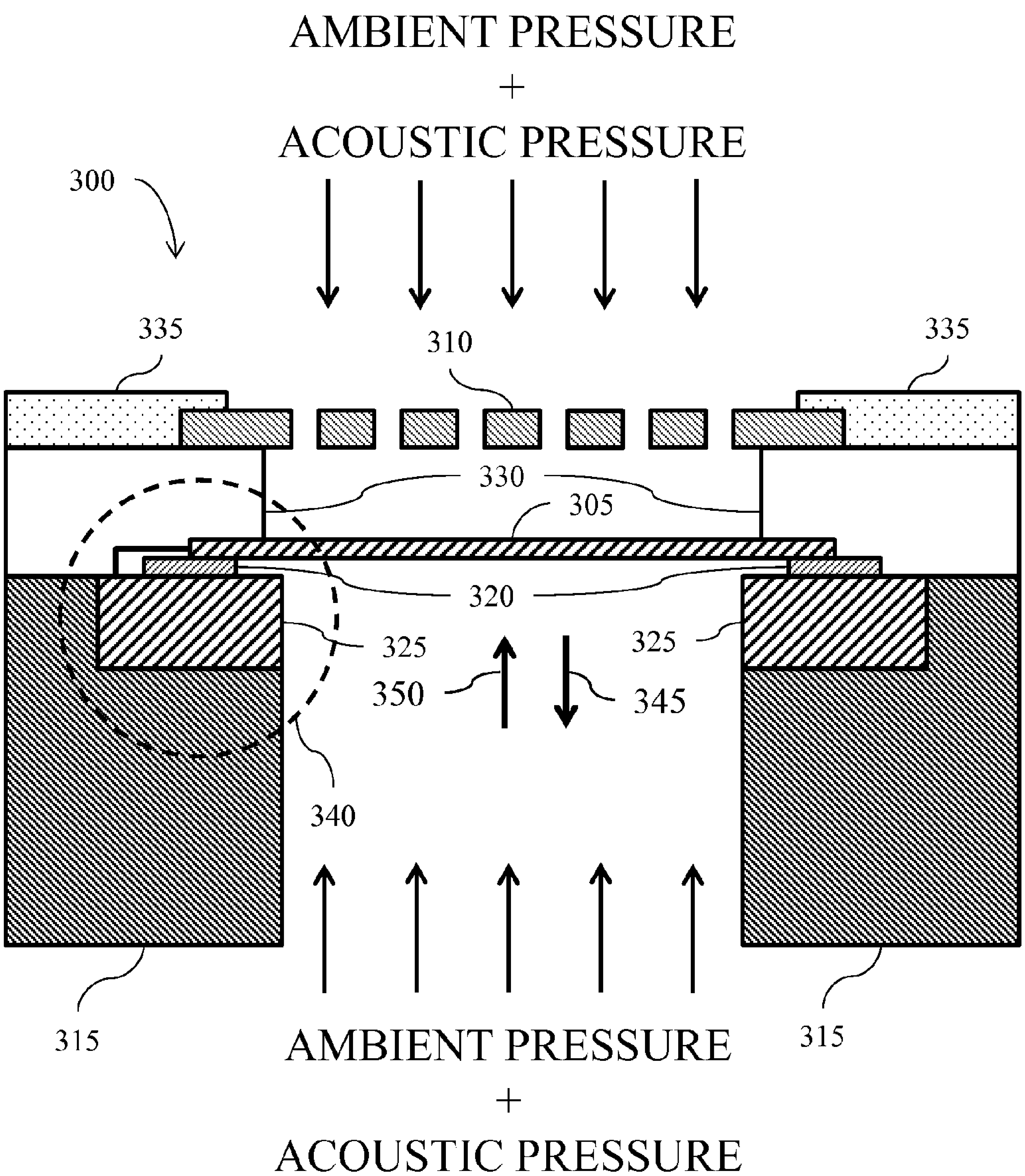


Fig. 2


AMBIENT PRESSURE
+
ACOUSTIC PRESSURE
300
335
310
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+
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Fig. 3

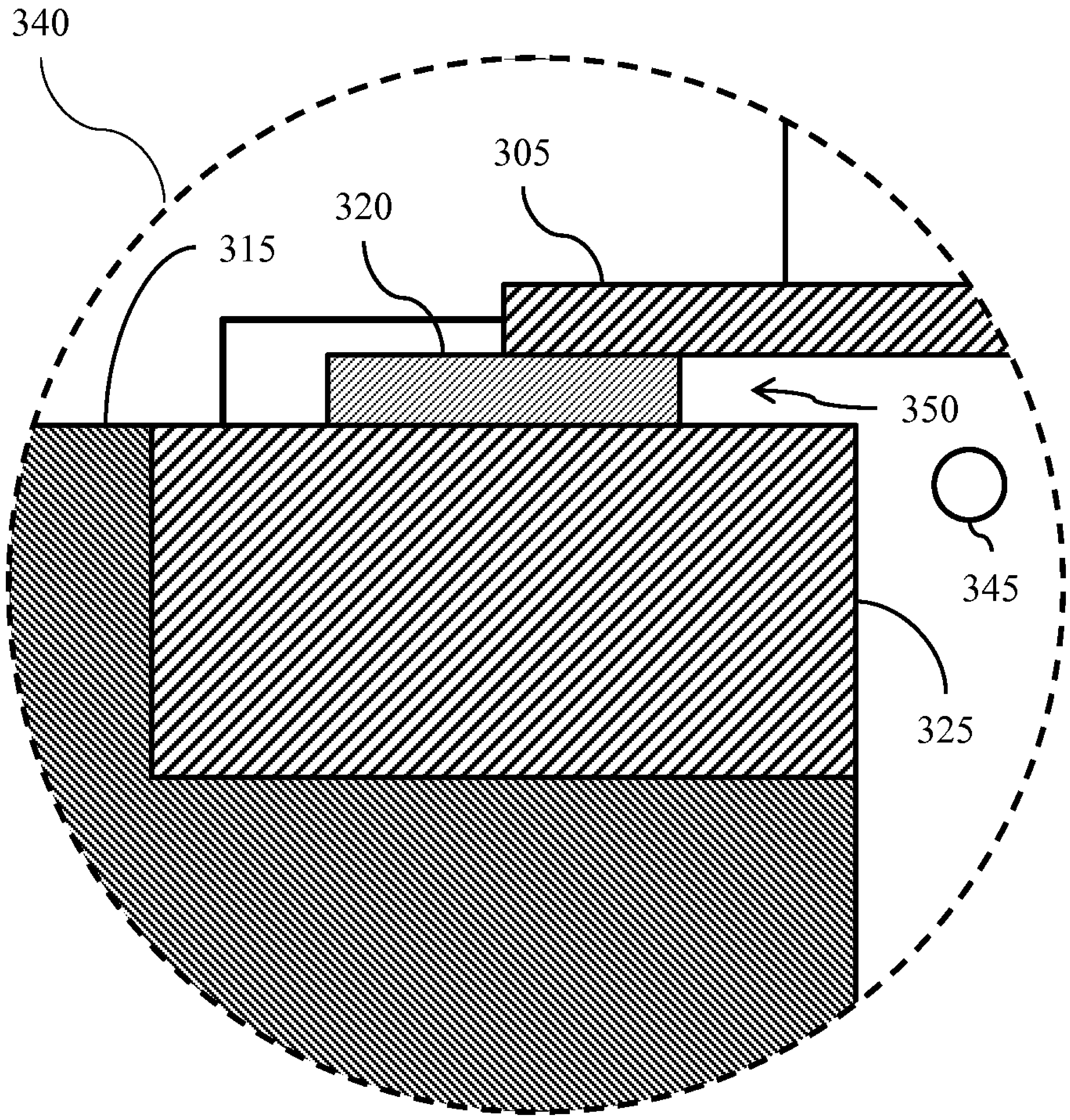

Fig. 4

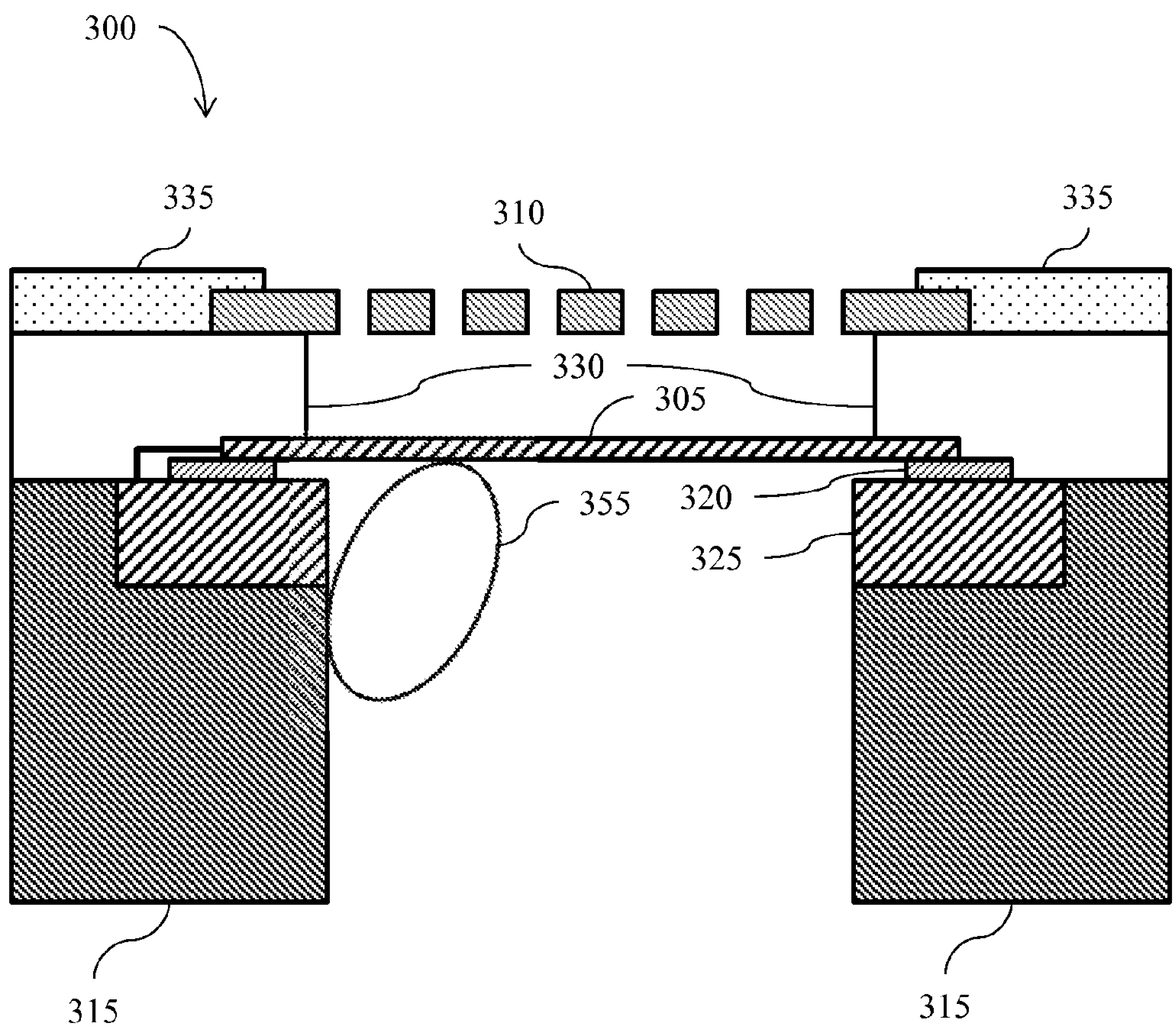

Fig. 5

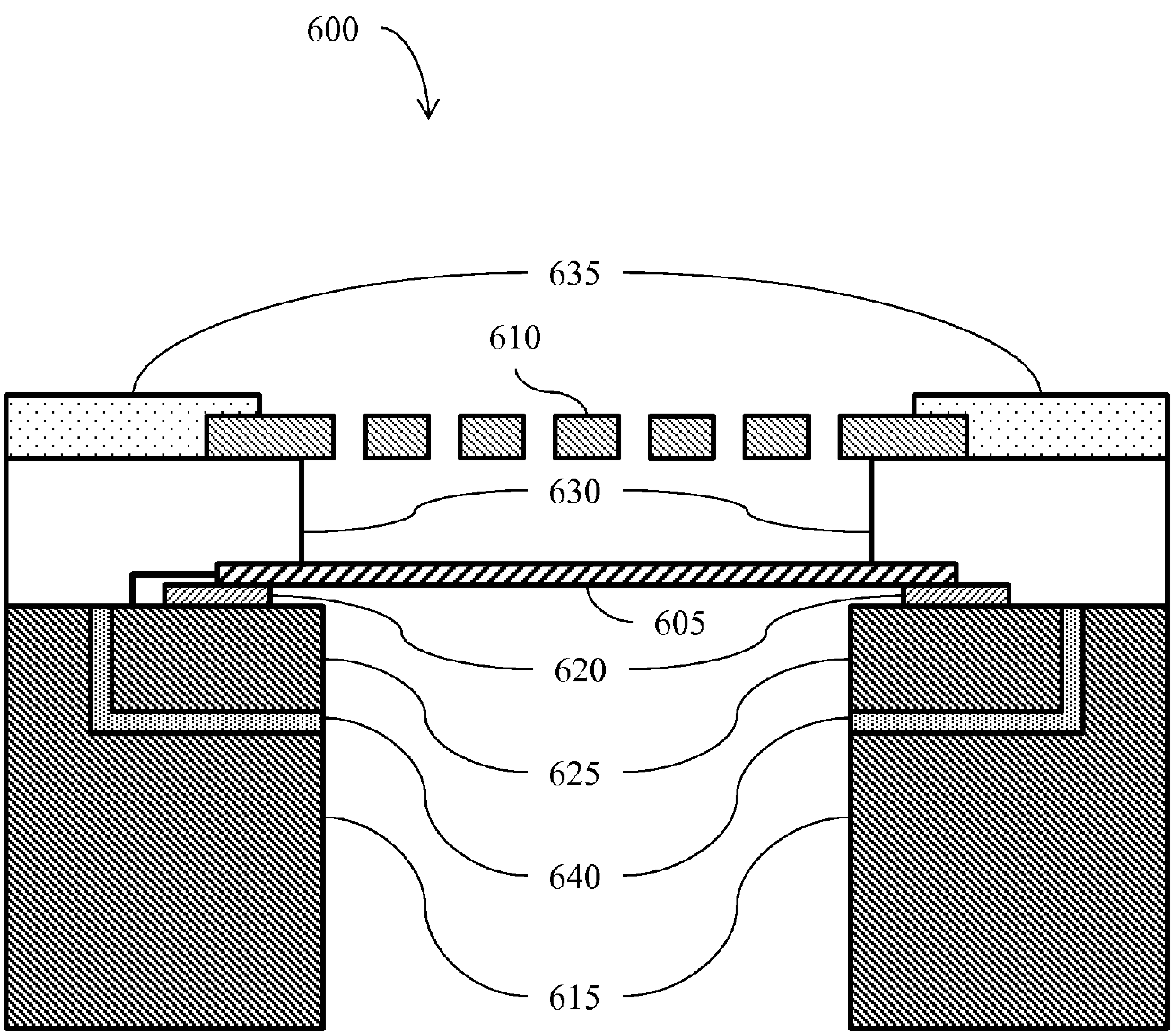

Fig. 6

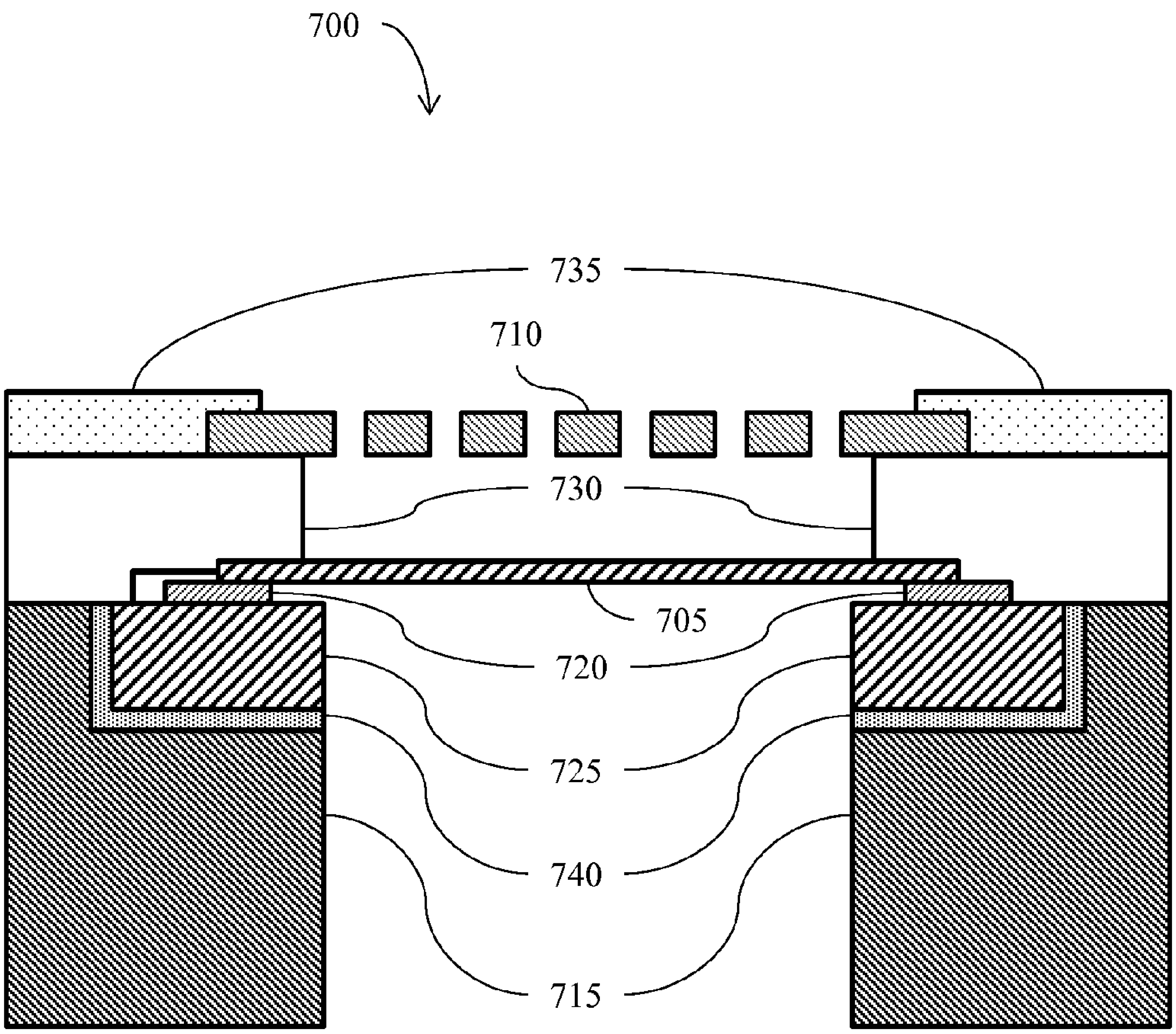

Fig. 7

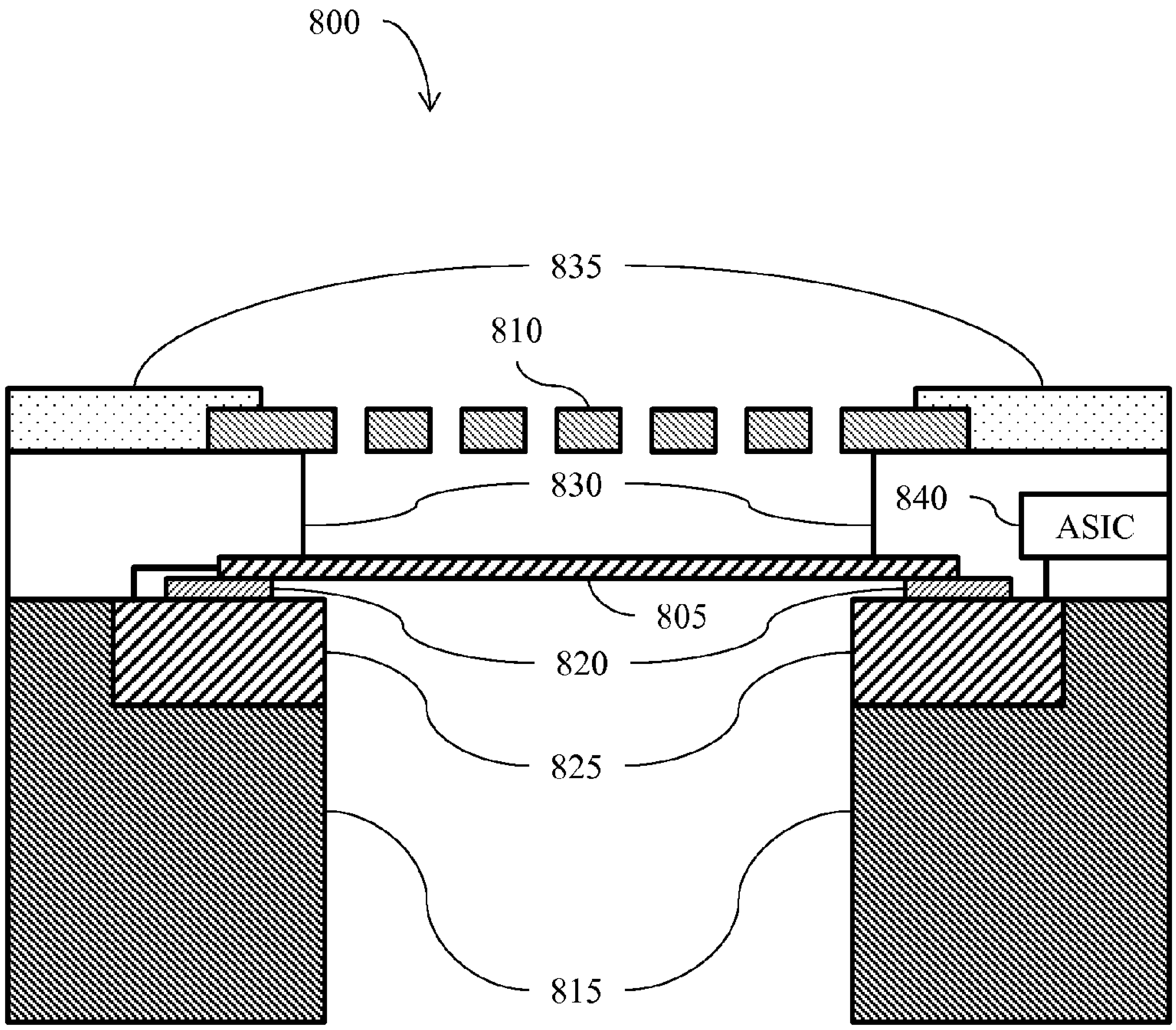

Fig. 8

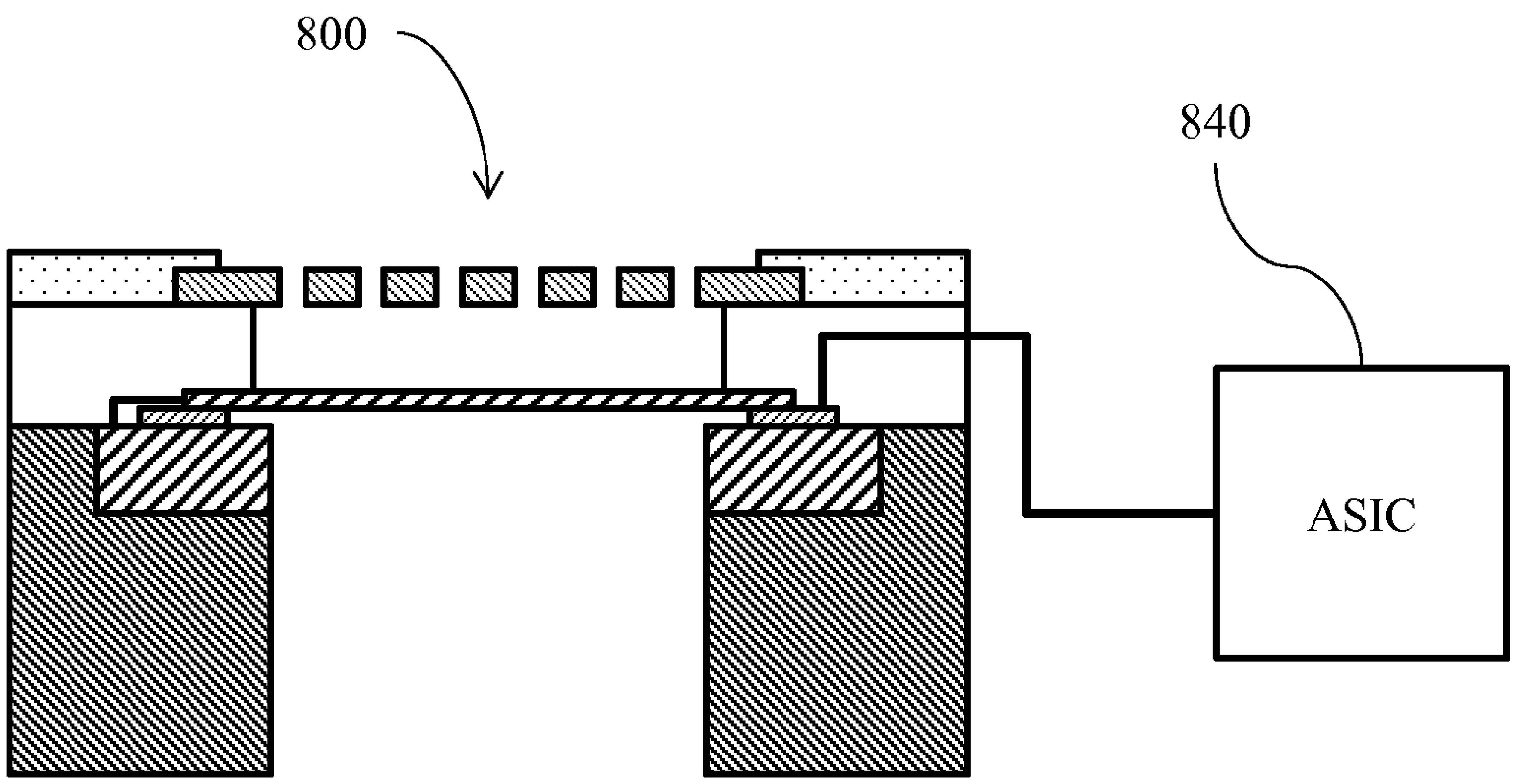

Fig. 9

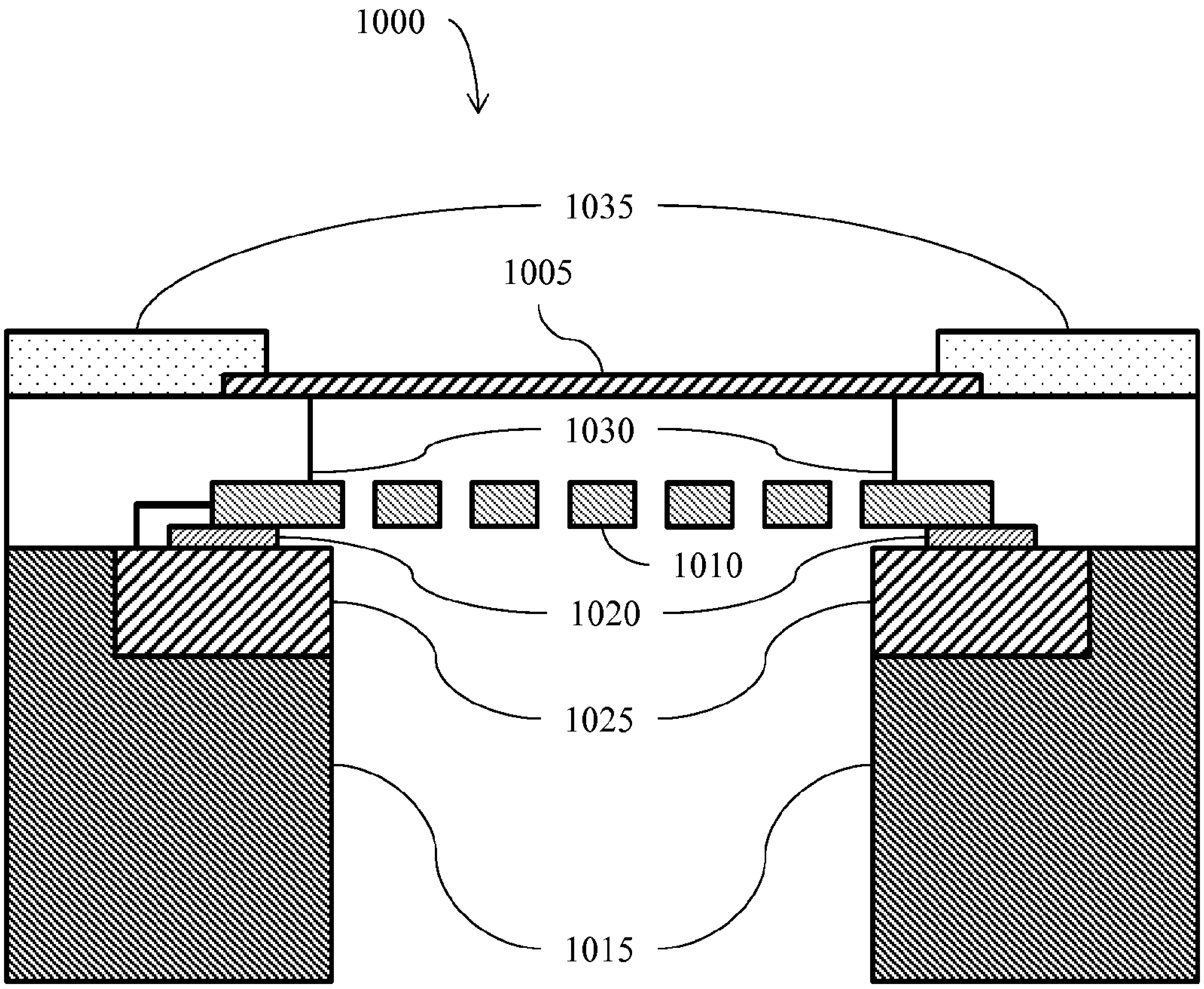

Fig. 10

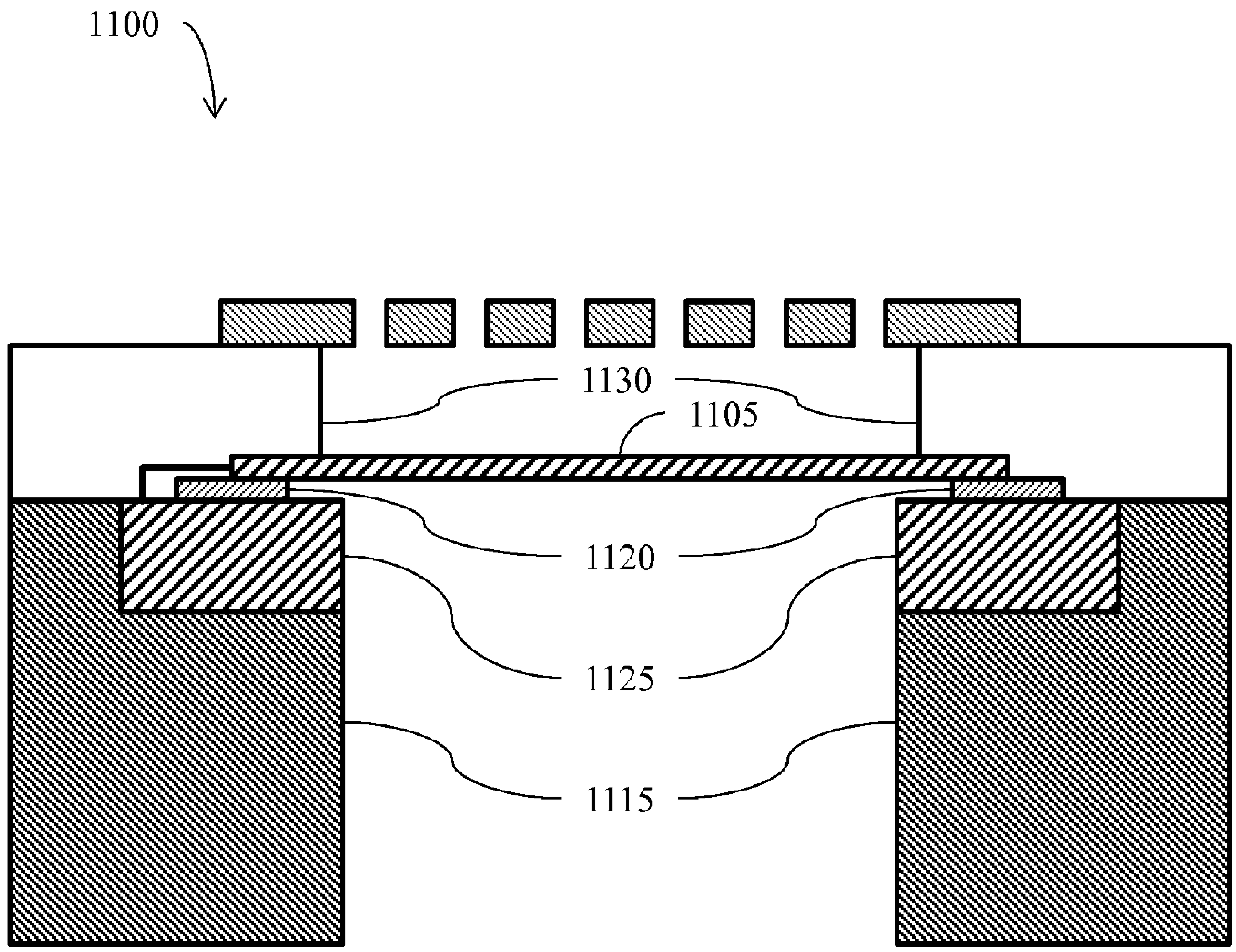

Fig. 11

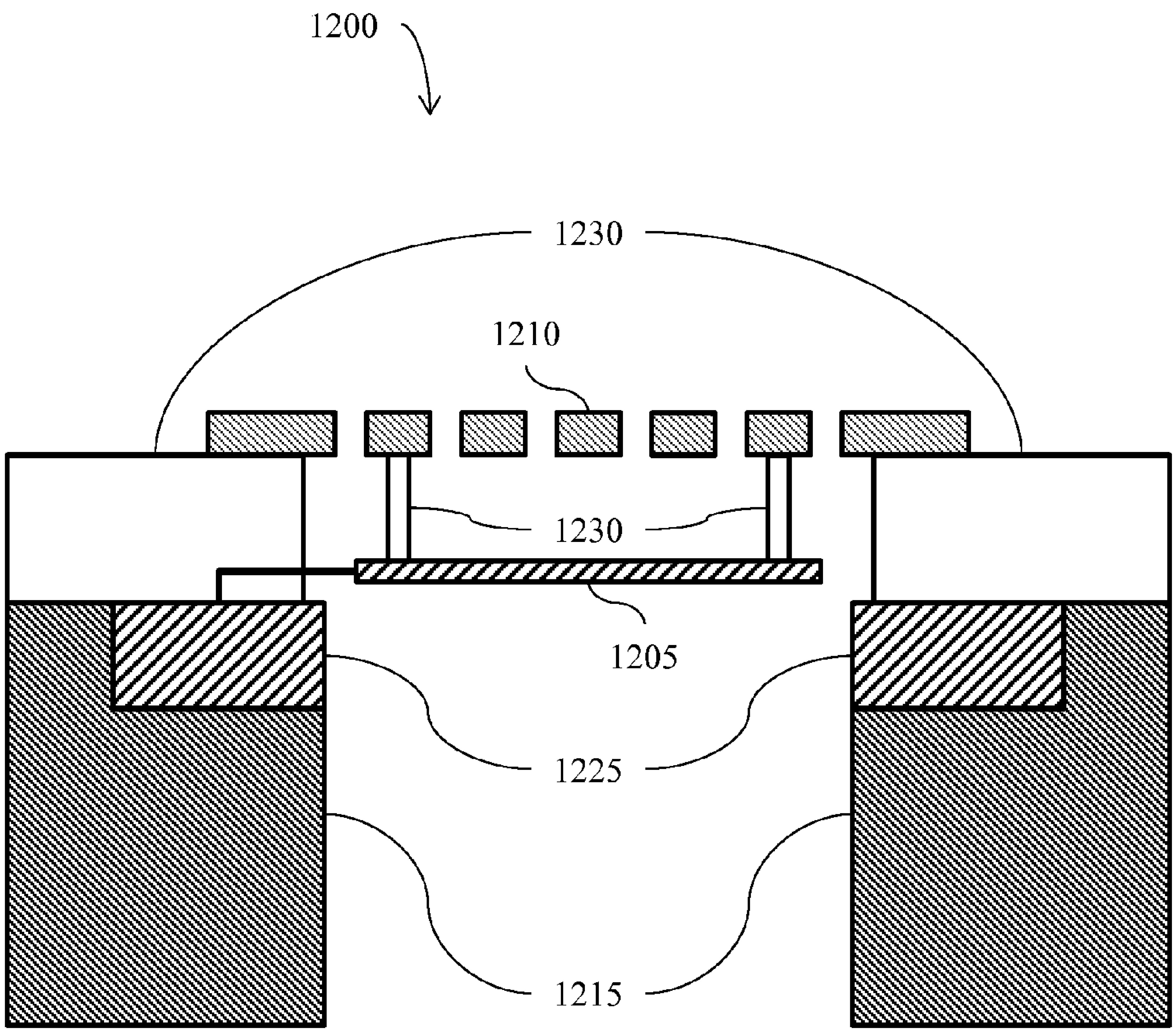

Fig. 12

DOPED SUBSTRATE REGIONS IN MEMS MICROPHONES

RELATED APPLICATIONS

This application claims priority to U.S. Provisional Application No. 61/973,507, filed on Apr. 1, 2014 and titled "DOPED SUBSTRATE REGIONS IN MEMS MICROPHONES," the entire contents of which is incorporated by reference.

BACKGROUND

Embodiments of the invention relate to preventing electrical leakage between a semiconductor substrate and an electrode in a MEMS microphone.

In a MEMS microphone, the overlap of an electrode (e.g., moveable membrane, stationary front plate) and a semiconductor substrate creates a susceptibility to electrical leakage from non-insulating particles (or other forms of leakage) that come into contact with the surfaces of both components. Insulating protection coatings are typically applied to MEMS microphones to prevent electrical leakage/shorts. However, conductive paths, caused by non-insulating particles, can be created during the manufacturing process prior to deposition of any coatings.

SUMMARY

One embodiment of the invention provides a MEMS microphone. The MEMS microphone includes a semiconductor substrate, an electrode, a first insulation layer, and a doped region. The doped region is implanted in at least a portion of the semiconductor substrate where the semiconductor substrate is in contact with the first insulation layer. The doped region is electrically coupled to the electrode. In some implementations, the semiconductor substrate includes N-type majority carriers and the doped region includes P-type majority carriers. In other implementations, the semiconductor substrate includes P-type majority carriers and the doped region includes N-type majority carriers. In some implementations, the electrode includes at least one type of electrode selected from a group consisting of a moveable electrode and a stationary electrode. In some implementations, the MEMS microphone further includes an application specific integrated circuit. In some implementations, the doped region is electrically coupled to the application specific integrated circuit. In other implementations, the doped region is electrically coupled to an application specific integrated circuit that is external to the MEMS microphone.

In another embodiment, a MEMS microphone with two insulation layers is provided. In one example, the MEMS microphone includes a semiconductor substrate, an electrode, a first insulation layer, a doped region, and a second insulation layer. The doped region is implanted in at least a portion of the semiconductor substrate where the semiconductor substrate is in contact with the first insulation layer. The doped region is electrically coupled to the electrode. The second insulation layer is formed between the semiconductor substrate and the doped region. The doped region includes a first plurality of majority carriers and the semiconductor substrate includes a second plurality of majority carriers. The first plurality of majority carriers and the second plurality of majority carriers include at least one type of majority carriers selected from a group consisting of P-type majority carriers and N-type majority carriers. In some implementations, the first plurality of majority carriers is a same type of majority carriers as the second plurality of majority carriers. In other implementations, the first plurality of majority carriers is a different type of majority carriers than the second plurality of majority carriers.

The invention further provides a method for preventing electrical leakage in a MEMS microphone. In one embodiment, the method includes forming a first insulation layer between a semiconductor substrate and an electrode. The method also includes implanting a doped region into the semiconductor substrate such that the doped region is provided in at least a portion of the semiconductor substrate where the semiconductor substrate is in contact with the first insulation layer. The method further includes electrically coupling the electrode to the doped region. In some implementations, the method also includes implanting P-type majority carriers into the doped region and N-type majority carriers into the semiconductor substrate. In other implementations, the method also includes implanting N-type majority carriers into the doped region and P-type majority carriers into the semiconductor substrate. In some implementations, the electrode includes at least one type of electrode selected from a group consisting of a moveable electrode and a stationary electrode. In some implementations, the method further includes electrically coupling the doped region to an application specific integrated circuit that is internal to the MEMS microphone. In other implementations, the method further includes electrically coupling the doped region to an application specific integrated circuit that is external to the MEMS microphone.

In another embodiment, the invention also provides a method for preventing electrical leakage in a MEMS microphone using, among other things, two insulation layers. In one example, the method includes forming a first insulation layer between a semiconductor substrate and an electrode. The method also includes implanting a doped region into the semiconductor substrate such that the doped region is provided in at least a portion of the semiconductor substrate where the semiconductor substrate is in contact with the first insulation layer. The method further includes electrically coupling the electrode to the doped region. The method also includes forming a second insulation layer between the semiconductor substrate and the doped region. In some implementations, the method further includes implanting a first plurality of majority carriers into the doped region and a second plurality of majority carriers into the semiconductor substrate. The first plurality of majority carriers and the second plurality of majority carriers include at least one type of majority carriers selected from a group consisting of P-type majority carriers and N-type majority carriers. In some implementations, the first plurality of majority carriers is a same type of majority carriers as the second plurality of majority carriers. In other implementations, the first plurality of majority carriers is a different type of majority carriers than the second plurality of majority carriers.

Other aspects of the invention will become apparent by consideration of the detailed description and accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a cross-sectional side view of a conventional MEMS microphone.

FIG. **2** is enlarged view of an area of FIG. **1**.

FIG. **3** is a cross-sectional side view of a MEMS microphone including a doped region.

FIG. **4** is enlarged view of an area of FIG. **3**.

FIG. **5** is a cross-sectional side view of a MEMS microphone including a doped region.

FIG. **6** is a cross-sectional side view of a MEMS microphone including a SOI layer.

FIG. **7** is a cross-sectional side view of a MEMS microphone including a SOI layer.

FIG. **8** is a cross-sectional side view of a MEMS microphone including an ASIC.

FIG. **9** is a system level view of a MEMS microphone and an ASIC.

FIG. **10** is a cross-sectional side view of a MEMS microphone including a doped region.

FIG. **11** is a cross-sectional side view of a MEMS microphone including a doped region.

FIG. **12** is a cross-sectional side view of a MEMS microphone including a doped region.

DETAILED DESCRIPTION

Before any embodiments of the invention are explained in detail, it is to be understood that the invention is not limited in its application to the details of construction and the arrangement of components set forth in the following description or illustrated in the following drawings. The invention is capable of other embodiments and of being practiced or of being carried out in various ways.

Also, it is to be understood that the phraseology and terminology used herein is for the purpose of description and should not be regarded as limiting. The use of "including," "comprising" or "having" and variations thereof herein is meant to encompass the items listed thereafter and equivalents thereof as well as additional items. The terms "mounted," "connected" and "coupled" are used broadly and encompass both direct and indirect mounting, connecting and coupling. Further, "connected" and "coupled" are not restricted to physical or mechanical connections or couplings, and can include electrical connections or couplings, whether direct or indirect.

It should also be noted that a plurality of different structural components may be utilized to implement the invention. Furthermore, and as described in subsequent paragraphs, the specific configurations illustrated in the drawings are intended to exemplify embodiments of the invention. Alternative configurations are possible.

FIG. **1** illustrates a conventional MEMS microphone **100**. The conventional MEMS microphone **100** includes a moveable electrode **105** (e.g., membrane), a stationary electrode **110** (e.g., front plate), a semiconductor substrate **115**, a first insulation layer **120**, a second insulation layer **125**, and a third insulation layer **130**. The moveable electrode **105** overlaps the semiconductor substrate **115**. This overlaps creates a gap **135** between the moveable electrode **105** and the semiconductor substrate **115**. The gap **135** creates a susceptibility to electrical leakage from non-insulating particles that come into contact with the surfaces of both components and to or other forms of leakage. Non-insulating particles include, for example, small fragments or thin released beams of silicon from a sidewall of a hole in the semiconductor substrate **115** and organic particles from photoresist that is used in manufacturing the MEMS microphone **100**.

FIG. **2** is an enlarged view of area **140** in FIG. **1**. As illustrated in FIG. **2**, an insulating protection coating **145** has been applied to the gap **135**. However, a non-insulating particle **150** is caught between the moveable electrode **105** and the semiconductor substrate **115**, causing a short.

A MEMS microphone **300** includes, among other components, a moveable electrode **305**, a stationary electrode **310**, a semiconductor substrate **315**, a first insulation layer **320**, a doped region **325**, an inter-metal dielectric ("IMD") layer **330**, and a passivation layer **335**, as illustrated in FIG. **3**. The moveable electrode **305** overlaps the semiconductor substrate **315**. The stationary electrode **310** is positioned above the moveable electrode **305**. In some implementations, the first insulation layer **320** includes a field oxide. In other implementations, the first insulation layer **320** includes a different type of oxide. For example, the first insulation layer **320** may include a thermal or plasma-based oxide (e.g., low pressure chemical vapor deposition oxide, plasma-enhanced chemical vapor deposition oxide). The IMD layer **330** is positioned between the moveable electrode **305** and the stationary electrode **310**. The IMD layer **330** electrically isolates metal lines in a CMOS process. In some implementations, the IMD layer **330** includes un-doped tetraethyl orthosilicate. The passivation layer **335** is positioned adjacent to the IMD layer **330** and is coupled to the stationary electrode **310**. The passivation layer **335** protects the oxides from contamination and humidity. Contamination and humidity cause current leakage and degrades the electrical performance of transistors, capacitors, etc. In some implementations, the passivation layer **335** includes silicon nitride. In other implementations, the passivation layer **335** includes silicon dioxide.

Acoustic and ambient pressures acting on the moveable electrode **305** cause movement of the moveable electrode **305** in the directions of arrow **345** and **350**. Movement of the moveable electrode **305** relative to the stationary electrode **310** causes changes in a capacitance between the moveable electrode **305** and the stationary electrode **310**. This changing capacitance generates an electric signal indicative of the acoustic and ambient pressures acting on the moveable electrode **305**.

FIG. **4** is an enlarged view of area **340** in FIG. **3**. The doped region **325** is implanted in the semiconductor substrate **315** such that it is in contact with the first insulation layer **320**. The doped region **325** is electrically coupled to the moveable electrode **305**. The semiconductor substrate **315** contains P-type majority carriers and the doped region **325** contains N-type majority carriers. In some implementations, the doped region **325** contains a concentration of approximately 1×10^{16} cm^{-3} N-type majority carriers. In some implementations, the semiconductor substrate **315** contains N-type majority carriers and the doped region **325** contains P-type majority carriers. In some implementations, the doped region **325** contains a concentration of approximately 1×10^{16} cm^{-3} P-type majority carriers. The doped region **325** prevents a non-insulating particle **345** from creating leakage paths in the gap **350** between the moveable electrode **305** and the semiconductor substrate **315**. P-type majority carriers include, for example, boron, aluminum, and any other group III element in the periodic table. N-type majority carriers include, for example, phosphorus, arsenic, and any other group V element in the periodic table.

The concentration of majority carriers and the depth of the doped region **325** influences the maximum voltage and non-insulating particle size that the doped region **325** is capable of preventing electrical leakage from. For example, a 12 micrometer deep doped region **325** containing N-type majority carriers is able to prevent up to 100 volts of electrical leakage. In FIG. **4**, the size of the non-insulating particle **345** is too small to create a leakage path between the moveable electrode **305** and the semiconductor substrate **315**. FIG. **5** illustrates a non-insulating particle **355** that is large enough to create a leakage path between the moveable electrode **305** and the semiconductor substrate **315**.

In some implementations, a MEMS microphone **600** includes, among other components, a moveable electrode **605**, a stationary electrode **610**, a semiconductor substrate **615**, a first insulation layer **620**, a doped region **625**, an IMD layer **630**, a passivation layer **635**, and a second insulation layer **640**, as illustrated in FIG. **6**. The moveable electrode **605** is electrically coupled to the doped region **625**. The first insulation layer **620** includes a field oxide. The second insulation layer includes a silicon-on-insulator ("SOI") wafer. The second insulation layer **640** is deposited between the semiconductor substrate **615** and the doped region **625**. The second insulation layer **640** provides electrical isolation between the semiconductor substrate **615** and the doped region **625**. Both the semiconductor substrate **615** and the doped region **625** contain P-type majority carriers. In some implementations, both the semiconductor substrate **615** and the doped region **625** contain N-type majority carriers.

In some implementations, a MEMS microphone **700** includes, among other components, a moveable electrode **705**, a stationary electrode **710**, a semiconductor substrate **715**, a first insulation layer **720**, a doped region **725**, an IMD layer **730**, a passivation layer **735**, and a second insulation layer **740**, as illustrated in FIG. **7**. The moveable electrode **705** is electrically coupled to the doped region **725**. The first insulation layer **720** includes a field oxide. The second insulation layer **740** includes an SOI wafer. The semiconductor substrate **715** contains P-type majority carriers and the doped region **725** contains N-type majority carriers. In some implementations, the semiconductor substrate **715** contains N-type majority carriers and the doped region **725** contains P-type majority carriers.

In some implementations, a MEMS microphone **800** includes, among other components, a moveable electrode **805**, a stationary electrode **810**, a semiconductor substrate **815**, a first insulation layer **820**, a doped region **825**, an IMD layer **830**, a passivation layer **835**, and an application specific integrated circuit ("ASIC") **840**, as illustrated in FIG. **8**. The moveable electrode **805** is electrically coupled to the doped region **825**. The first insulation layer **820** includes a field oxide. The ASIC **840** is integrated into the MEMS microphone **800**, for example, in the IMD layer **830**. The ASIC **840** is electrically coupled to the doped region **825**. The doped region **825** can introduce parasitics (e.g., capacitance) between the doped region **825** and the semiconductor substrate **815**. In some implementations, the ASIC **840** is configured to support the added parasitics. In some implementations, the ASIC **840** is separate from the MEMS microphone **800**, as illustrated in FIG. **9**.

In some implementations, a MEMS microphone **1000** includes, among other components, a moveable electrode **1005**, a stationary electrode **1010**, a semiconductor substrate **1015**, a first insulation layer **1020**, a doped region **1025**, an IMD layer **1030**, and a passivation layer **1035**, as illustrated in FIG. **10**. The first insulation layer **1020** includes a field oxide. The stationary electrode **1010** overlaps the semiconductor substrate **1015**. The moveable electrode **1005** is positioned above the stationary electrode **1010**. The stationary electrode **1010** is electrically coupled to the doped region **1025**. The IMD layer **1030** is positioned between the moveable electrode **1005** and the stationary electrode **1010**. The passivation layer **1035** is positioned adjacent to the IMD layer **1030** and is coupled to the moveable electrode **1005**. The semiconductor substrate **1015** contains P-type majority carriers and the doped region **1025** contains N-type majority carriers. In some implementations, the semiconductor substrate **1015** contains N-type majority carriers and the doped region **1025** contains P-type majority carriers.

The MEMS microphones discussed above are designed for ASIC processes. Doped regions may also be used in a MEMS microphone **1100** designed for a non-ASIC process. In some implementations, the MEMS microphone **1100** includes, among other components, a moveable electrode **1105**, a stationary electrode **1110**, a semiconductor substrate **1115**, a first insulation layer **1120**, a doped region **1125**, and an IMD layer **1130**, as illustrated in FIG. **11**. The moveable electrode **1105** is electrically coupled to the doped region **1125**. In some embodiments, the first insulation layer **1120** includes a field oxide. In other embodiments, the first insulation layer **1120** includes, for example, a different type of oxide, or a type of nitride. The moveable electrode **1105** overlaps the semiconductor substrate **1115**. The stationary electrode **1110** is positioned above the moveable electrode **1105**. The IMD layer **1130** is positioned between the moveable electrode **1105** and the stationary electrode **1110**. The IMD layer **1130** includes, for example, silicon oxide or nitride.

In some implementations, the MEMS microphone **1200** includes, among other components, a moveable electrode **1205**, a stationary electrode **1210**, a semiconductor substrate **1215**, a doped region **1225**, and an IMD layer **1230**, as illustrated in FIG. **12**. The moveable electrode **1205** does not overlap the semiconductor substrate **1215**. The moveable electrode **1205** is electrically coupled to the doped region **1205**. The stationary electrode **1210** is positioned above the moveable electrode **1205**. The IMD layer **1230** is positioned between the moveable electrode **1205** and the stationary electrode **1210**. The moveable electrode **1205** is physically coupled to the stationary electrode **1210** via the IMD layer **1230**. The IMD layer **1230** electrically isolates the moveable electrode **1205** from the stationary electrode **1210**. In some implementations, the IMD layer **1230** includes un-doped tetraethyl orthosilicate. In other implementations, the IMD layer **1230** includes, for example, silicon oxide or nitride.

Thus, the invention provides, among other things, systems and methods of preventing electrical leakage in MEMS microphones. Various features and advantages of the invention are set forth in the following claims.

What is claimed is:

1. A MEMS microphone comprising:

a semiconductor substrate;

an electrode;

a first insulation layer, the first insulation layer formed between the electrode and the semiconductor substrate;

a doped region, the doped region implanted in at least a portion of the semiconductor substrate; and

a second insulation layer is formed between the semiconductor substrate and the doped region,

wherein the semiconductor substrate is in contact with the first insulation layer, and the doped region is electrically coupled to the electrode.

2. The MEMS microphone according to claim **1**, wherein the doped region includes P-type majority carriers and the semiconductor substrate includes N-type majority carriers.

3. The MEMS microphone according to claim **1**, wherein the doped region includes N-type majority carriers and the semiconductor substrate includes P-type majority carriers.

4. The MEMS microphone according to claim **1**, wherein the doped region includes a first plurality of majority carriers and the semiconductor substrate includes a second plurality of majority carriers, and wherein the first plurality of majority carriers and the second plurality of majority carriers include at least one type of majority carriers selected from a group consisting of P-type majority carriers and N-type majority carriers.

5. The MEMS microphone according to claim **4**, wherein the first plurality of majority carriers is a same type of majority carriers as the second plurality of majority carriers.

6. The MEMS microphone according to claim **4**, wherein the first plurality of majority carriers is a different type of majority carriers than the second plurality of majority carriers.

7. The MEMS microphone according to claim **1**, wherein the electrode includes at least one type of electrode selected from a group consisting of a moveable electrode and a stationary electrode.

8. The MEMS microphone according to claim **1**, further comprising an application specific integrated circuit, wherein the doped region is electrically coupled to the application specific integrated circuit.

9. The MEMS microphone according to claim **1**, wherein the doped region is electrically coupled to an application specific integrated circuit that is external to the MEMS microphone.

10. A method for preventing electrical leakage in a MEMS microphone, the method comprising:

forming a first insulation layer between a semiconductor substrate and an electrode;

implanting a doped region into the semiconductor substrate such that the doped region is provided in at least a portion of the semiconductor substrate where the semiconductor substrate is in contact with the first insulation layer;

forming a second insulation layer between the semiconductor substrate and the doped region; and

electrically coupling the electrode to the doped region.

11. The method according to claim **10**, further comprising implanting P-type majority carriers into the doped region and N-type majority carriers into the semiconductor substrate.

12. The method according to claim **10**, further comprising implanting N-type majority carriers into the doped region and P-type majority carriers into the semiconductor substrate.

13. The method according to claim **10**, further comprising implanting a first plurality of majority carriers into the doped region and a second plurality of majority carriers into the semiconductor substrate, wherein the first plurality of majority carriers and the second plurality of majority carriers include at least one type of majority carriers selected from a group consisting of P-type majority carriers and N-type majority carriers.

14. The method according to claim **13**, wherein the first plurality of majority carriers is a same type of majority carriers as the second plurality of majority carriers.

15. The method according to claim **13**, wherein the first plurality of majority carriers is a different type of majority carriers than the second plurality of majority carriers.

16. The method according to claim **10**, wherein the electrode includes at least one type of electrode selected from a group consisting of a moveable electrode and a stationary electrode.

17. The method according to claim **10**, further comprising electrically coupling the doped region to an application specific integrated circuit that is internal to the MEMS microphone.

18. The method according to claim **10**, further comprising electrically coupling the doped region to an application specific integrated circuit that is external to the MEMS microphone.

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